NASA-FISK UNIVERSITY
CENTER FOR PHOTONIC MATERIALS AND DEVICES
PROGRESS REPORT FOR THE PERIOD
JANUARY 1, 1992-DECEMBER 31,1996

1. EXECUTIVE SUMMARY

1. INTRODUCTION

As stated in the original proposal the center aimed at: 1) improving and expanding the existent operations of the University to consolidate them into a stable Center of Excellence able to contribute with widely recognized quality science and technologies relevant to NASA and produced in a minority institution; 2) to attract an increased number of traditionally underrepresented students, both graduate and undergraduate, to enter the pipeline leading to an advanced degree and to motivate them to pursue careers in fields relevant to the NASA mission.

1.2. AREAS OF RESEARCH

The laboratories and personnel were assigned to four groups led by PI's, although the unified goals of the Center lead to some sharing of personnel and extensive sharing of characterization equipment. Microgravity conditions were especially taken in account in two ways: 1) for creating new materials, or improving known ones, with better characteristics for their use in space missions (weight, reliability, temperature and radiation resistance, etc: 2) for materials which could only be produced in space with better characteristics (homogeneity, crystal perfection, etc.)

Group 1, "Nanomaterials" was led by Dr. D.O. Henderson and emphasized both basic and applied research: 1) to produce and characterize the thermodynamics and optical properties of nanophase materials with an emphasis on studying how material properties evolve as they pass through a subcritical nucleus to a stable nanocrystal, and 2) develop applications of those materials in technologies of interest to NASA Enterprises. The materials studied included metal colloids and semiconductor quantum dots. Collaborations through NASA Grants and Contracts were in effect with MSFC and LeRC, and also with DOE,

Group 2, "Semiconductor Crystals and Films" led by Dr. A. Burger aimed at: 1) understanding the effects of growth and conditions on the quality of crystals and 2) fabricating devices using optimized crystals and films. Crystals studied included heavy metal iodides and binary and ternary II-VI compounds, which have been used to fabricate x-ray and gamma-ray detectors. There was close collaboration with MSFC in this research and fabricated detectors were planned for experiments in GSFC flights.

Group 3, "Optical Materials" led by Dr. S. Morgan aimed at developing new optical materials relevant to the Mission to Planet Earth and Aeronautics Enterprises. They included oxide glasses for fiber lasers and fiber sensor applications, rare-earth doped glass-ceramics for thermophotovoltaic applications and II-VI semiconductor crystals for optical signal processing. Grants from NSF and USAF/Wright Lab supplemented the Center resources.

Group 4, "Surface Physics", lead by Dr. W. E. Collins operated the ultrahigh-vacuum surfaces analyses by a diversity of techniques (STM, XPS, MS, Auger) and most Scanning Probe Microscopies. The surfaces of materials produced and manipulated (etched, doped, electroded, polished, etc) by the other Groups were characterized, which made important contributions to the technologies used for the fabrication of devices.

1.3. UNIVERSITY RESOURCES

The University has a long tradition of support for research. An interdepartmental Molecular Spectroscopy Laboratory was created in 1960 and provided with facilities, operation costs and release time for its Director. An Office of Sponsored Research was organized in 1990. Two new Physics Professor (one tenured) were appointed in 1991 for the purpose of expanding research (far exceeding the teaching needs of the Department). Two new minority Professor positions; which included release time to do research at the Center, were offered in 1994, although only one could be filled (the other will be filled when a suitable candidate is available). In October 1996, Dr. John Caulfield, a world renown authority on photonics applications was appointed Research Professor of Physics and started collaborating with the Center research. The University contributed $100,000 to the renewal of the 3-story building now mostly occupied by the Center, with student scholarships and with partial waiving of indirect costs.

1.4. PARTNERSHIPS

The existence of the Center generated a rapid growth of contributions made by NASA installations, other Federal agencies, industry, and one Foundation, widely exceeding the proposed amounts in the original proposal, as shown in the following table.

Year	University		Other Sources		%
	Projected	Actual	Projected	Actual	Performance
1992	30,360	72,060	18,850	95,316	340%
1993	37,356	144,782	119,080	191,043	215%
1994	41,581	41,886	119,584	362,683	251%
1995	43,723	65,593	120,113	1,011,299	557%
1996	46,017	154,753	120,699	1,118,862	664%

Included in this leverage are $403,149 of equipment which has provided the very wide field of technical capabilities that the Center possesses now and also new personnel that contributed with new fields, such as Scanning Probe Microscopies and nanomaterials. Notice that the University contributed in 1993 to this expansion with funds exceeding their original commitment, including funds for the remodeling of a building in order to make it usable as research laboratories and investigators and graduate student offices. This allowed the Center to

move from the 5 rooms previously used in the basement of the Chemistry building to more than 50 rooms in a 3-story building with adequate power and water resources to serve the large increase of instrumentation acquired during the 5 years.

Detailed justification of the contributions of the University and other sources can be found in the Annual Progress Reports and the Recompetition Proposal for extending the period of NASA support to the Center.

1.5. STUDENTS' PROGRAM

The Center used the awarded funds for three categories of students: 1) graduate students aiming at a Master Degree; 2) undergraduates participating in research up to 15 hours a week; 3) undergraduates from Fisk and other minority institutions participating full-time in a summer program of study and research.

The existence of a high quality research facility attracted leverage funding from other NASA installations, other Federal agencies and the Kellogg Foundation. The progress is reflected in the following table of students who used the Center for their learning and research.

YEAR	GRADUATE			UNDERGRADUATE		
	Projected	Actual		Projected	Actual	
		*AA	Other		*AA	Other
1992	7	2	5	7	6	2
1993	7	6	2	7	11	--
1994	7	8	2	7	16	--
1995	7	12	1	7	28	0
1996	7	11	0	7	28	0

***African-Americans**

2. RESEARCH RESULTS

2.1. NANOCRYSTALS

This particular part of the research program produced 31 publications in refereed journals and 30 presentations at international conferences. The research supported under this program drew the attention of the nanophase community which resulted in 5 invited talks in 1995-96 at National Laboratories and Universities.

Some of the more significant findings from NASA sponsored research are: (1) the discovery of a cross-over transition for nanophase $NaNO_3$ material confined in a sized, geometrically restricted matrix (J. Chem. Phys. 100, 7749 1994). These results demonstrated that

$NaNO_3$ clusters with a size less than that of the critical nucleus are amorphous; when the particle size approaches 50Å, long range order sets in and the phonon spectra and the melting and freezing transitions begin to resemble those of the bulk. (2) Another investigation resolved to some extent a long standing controversy concerning the nucleation of geometrically confined materials (in porous glass) and was recently published (Phys. Rev. B53, 6041 1996). Nucleation was found to occur from the pore center and propagate through the pores and toward the pore wall. These investigations also demonstrated that percolation occurred during the solidification process although the confined material had a 10% shrinkage upon solidification. (3) Our phonon spectra on several III-V quantum dots showed that a peak appearing between the transverse and longitudinal optical modes could be attributed to the surface phonon. These surface phonons showed good agreement with Frŏlich's theory (submitted to Phys. Rev. B).

New collaborations have also emerged from NASA support, two of which are at NASA enterprises; NASA Lewis, Photovoltaics Branch, and NASA/MSFC, Polymer Division. Other collaborations are spread across the United States and some collaborations have been initiated in Europe. All of the collaborations center about nanophase materials. Such collaborations have strengthened our research program on nanophase materials and are expected to continue and expand into the future.

2.2. OPTICAL MATERIALS

The initial goals for glass research within the Center, as stated in the original proposal, were (i) to use infrared and Raman spectroscopy in conjunction with nonlinear index of refraction measurements to investigate the relationships between the structure and composition of a glass and its nonlinear optical properties, and (ii) to apply these techniques to materials which have good figures-of-merit for all optical switching and signal processing devices. Specific classes of materials to be studied were ion-implanted glasses, II-VI semiconductor-doped glasses containing highly polarizable ions. Results from this research have included.

- Characterization of Pb- implanted fused silica as a function of implantation dose and thermal annealing [Proc. SPIE 1761, 191 (1992); J. Non-Cryst. Sol. 152, 258 (1993)]; the nonlinear optical response of Sb and Bi-implanted fused silica as a function of implantation dose and of annealing time, temperature and atmosphere [Mat. Res. Soc. Symp. Proc. 279, 327 (1993); Mat. Res. Soc. Symp. Proc. 316, 469 (1994); Optical Materials 4, 675 (1995)].

- Atomic force microscopy for size determination of II-VI nanocrystals in silicate glass [Am. Ceram. Soc. 1993] and Raman spectroscopy of CdS_xSe_{1-x} nanocrystals in a silicate glass matrix [Mater. Res. Soc. Symp. Proc. 358, 229 (1995)].

- The development of a model to explain enhanced low frequency Raman intensities in bulk lead haloborate glasses [J. Chem. Phys. 101(3), 1767 (1194)] and Raman scattering and Z-scan measurements used to determine the vibrational and electronic contributions to the nonlinear index of refraction in lead borate glasses [J. Non-Cryst. Sol. 185, 127 (1995)].

During years four and five of the current grant, research objectives were expanded to include rare-earth doped heavy metal oxide glasses for fiber laser applications, and transition metal doped II-VI semiconductor crystals for photorefractive applications. The facilities and expertise developed in this research have also been applied to materials being studied in other Center projects as well. Since the inception of the Center, this area of research has resulted in 22 publications and 14 presentations at national or international meetings.

2.3. SEMICONDUCTOR CRYSTALS

In this area of research the program produced more than 33 publications, 64 conference presentations, one patent (U.S. Patent 5,365,876 with Dr. Don O. Nason of EG&G Inc.) and two book chapters [("Semiconductors for Room Temperature X and Gamma Ray Detectors" in the Semiconductors and Semimetals series, Vol 43, Chapter 5 (Crystal Growth of Mercuric Iodide) with D. Nason, L. van den Berg and M. Schieber and Chapter 12 (Lead Iodide Crystals and Detectors) with J.C. Lund and F. Olschner, Academic Press, 1995)]. We currently have a vigorous research effort being carried out in the purification of electronic materials and growth and characterization of semiconducting crystals such as HgI_2, PbI_2, ZnCdTe, ZnSe, CdSSe, and CdSeTe.

We have been able to develop an extensive NASA relevant capability that will ensure a successful performance in this investigation. The additions made in the research program as a direct result of the presence of the Center are: crystal growth of mercuric iodide by physical vapor transport, processing novel heavy metal iodides and II-VI compound binary and ternary single crystals; characterization of electrical, optical and thermal properties of these compounds; design, fabrication and evaluation of electronic devices (room temperature x-and gamma ray detectors, photodetectors); development of optical, in-situ characterization during the crystal growth process.

New instrumentation was acquired, and special equipment was designed and built for the purification, synthesis and crystal growth of photonic materials, and for their characterization. As a result, the research group at Fisk presently involved in this activity became internationally recognized as one of the major institutions conducting research in the area of wide bandgap semiconductors for room temperature X-ray and gamma- ray detectors. The research activity is conducted in the following labs:

A) Crystal Growth Laboratory, equipped with synthesis, purification and crystal growth systems, suitable for the processing of wide bandgap crystals. During the past five years we were able to expand to thin film technologies by acquiring, with Center funds, an RF sputtering system.

B) Surface Science Laboratory, with recently acquired X-ray photoelectron/Auger spectroscopy (XPS/AUGER) and associated UHV equipment. Since the establishment of the Center for Photonics, several atomic force/scanning tunneling microscopy (AFM/STM) systems have been added.

C) Characterization Laboratory, equipped with modern instrumentation acquired or developed at Fisk for the surface and bulk characterization of materials, crystals, and devices.

3. EDUCATION RESULTS

The "Students' Program" section (1.5) of the Introduction mentions the Center activities which included student training in research. It also shows the annual increase in the participation of African-American students. The Appendix #1 (Uniform Outcomes Data) shows their contribution to 25 publications and 41 presentations at national conferences. Of particular interest was the development of the annual summer workshops, the activities of which are described in Appendix 3. Additional information is presented in the following table.

Summer Student Participation Analysis (1994-96)

Year	1994	1995	1996
# Students	15	18	19(23)
# Universities	4	8	13
# States	11	12	14
Classification			
Graduate	2	--	0
Freshman	2	9	3
Sophomore	5	4	8
Junior	3	1	6
Senior	3	5 (2)	2
Gender			
Male	8	8	7
Female	7	10	12
Ethnic Background			
Black	15	18	17
Hispanic	0	0	1
White	0	0	1

The best example of the influence of the summer workshop on students' decisions is given by 5 Fisk students who obtained their Bachelor degrees in 1993, attended the summer workshop and decided to pursue a Master Degree that they obtained in 1995. Four of them are now in Ph.D. programs. To increase the students' interest in subjects related to NASA activities, two new undergraduate courses (Materials Science and Exploration of the Solar System) were approved for the curriculum.

All the students participating in the summer workshop visited Marshall Space Flight Center. Most of the undergraduates participating in research during the academic year attended the National Conferences of Black Physics Students and some attended the National Conferences of Undergraduate Research. The graduate students attended all the National Conferences where they were listed as co-authors of research papers.

4. MISCELLANEOUS ACTIVITIES

4.1 Peer Reviews

Research papers were reviewed for the Journal of Non-Crystalline Solids, the Journal of Vacuum Science and Technology, the Journal of Applied Science, Applied Physics Letters, the Journal of Scanning Microscopy, the Journal of Crystal Growth, the Journal of Nuclear Instruments and Methods in Physics Research, the Journal of the Optical Society of America, Physics and Chemistry of Solids and Photonic Technology Letters.

4.2 Review Panels

E. Silberman served in panels for evaluation of proposals for NASA/MURC CAN-DEOP-51-1 (2 levels), the National Photonic Skills Standards for Technicians and the DOE/HBCU Nuclear Energy Training Program.
D. O. Henderson reviewed proposal for the Federal Aviation Administration.
A. Burger was appointed for the NASA/GSFC Planetary Instrument Definition and Development Panel.

4.3 Internal Seminars

12 invited speakers lectured for faculty and students in 1995-96.

4.4 External Lectures and Seminars

Were conducted at Alabama A&M University, the University of Texas El Paso, Texas Technological University, NASA/LeRC, NASA/MSFC, NASA/GFSC, Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, the University of Massachusetts at Lovell, Argonne National Laboratory, Wright-Patterson AFB Laboratory and the University of Alabama, Huntsville.

4.5 Promotion and Recruiting

- Home Page in WWW (http:/www.fisk.edu/nasa.html
- Listing in Synergistic "Technologies Database of Research Centers for the Electronic Industry"
- Listing in the "Optoelectronics Research Center Profile Directory
- Hosted the National Conference of Black Physics Students (February, 1996)
- Co-Hosted the National Conference of Black Physicists (March, 1996)
- Produced brochures for advertising the Center research and students' opportunities.
- Lectured in high schools with high African-American students presence
- Appointed an Advisory Committee with participation of University, NASA, DOE and Industrial personnel (Appendix 2)

APPENDIX 1

NASA Minority University Research Programs
Uniform Outcomes Data

1992 - 1996 Research and Technology Report

BACKGROUND

Grant Number: NAGW-2925

Grant or Project Title: Center for Photonic Materials and Devices

MUREP Research Program (check one):
University Research Centers (URC) X
Institutional Research Awards (IRA) ____
Faculty Awards for Research (FAR) ____
Unsolicited ____

Principal Investigator

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Home Page URL: http://www.fisk.edu/nasa.html

NASA Installation from which award was procured (check one):

Ames Research Center ___	Kennedy Space Center ___	Stennis Space Center ___
Dryden Flight Research Center ___	Langley Research Center ___	Jet Propulsion Laboratory ___
Goddard Space Flight Center ___	Lewis Research Center ___	NASA Headquarters X
Johnson Space Center ___	Marshall Space Flight Center ___	

NASA Enterprises which your research supports:

Check Primary Enterprise	Check others which are relevant
Aeronautics ___	Aeronautics X
Human Exploration and Development of Space X	Human Exploration and Development of Space ___
Mission to Planet Earth ___	Mission to Planet Earth ___
Space Science ___	Space Science X

NASA MUREP INVESTMENT

Report expenditures of NASA MUREP award funds, pro-rated for the reporting period.

Enter MUREP-award Dollars expended for:	Equipment (direct purchase cost only)		$ 240,342
	Student support (including any fringes and/or indirect charges) for	Undergraduates	$ 49,120
		Master's Students	$ 290,750
		Doctoral Students	$ ---
	Research (all other expenditures)		$ 2,457,387
	Total (Must equal sum of above lines)		$ 3,037,599

STUDENT OUTCOMES

Report student activities during the reporting period.

Enter Number of MUREP-Funded Students in Each Category				
		UNDERGRADS	MASTER'S	DOCTORAL
Participants in Research	All	91	48	---
	UMD	89	36	---
Degrees Awarded	All	15	15	---
	UMD	15	11	---
Post-Degree Plans of Degree Recipients				
Continuing for Next Degree	All	12	11	---
	UMD	12	8	---
Employed in NASA-Related Field	All	0	0	---
	UMD	0	0	---

"MUREP-Funded" = Any student receiving partial or full support from your NASA MUREP grant during the reporting period

ALL = Any student receiving partial or full support from your NASA MUREP grant during the reporting period.

UMD = Underrepresented Minority (African American, Hispanic, Native American, or Pacific Islander) and/or Students with Disabilities.

RESEARCH OUTCOMES

Report only events and activities which occurred during the reporting period.

Enter Numbers of:			
Non-Student Investigators	Faculty		10
	Research Associates		3
	Post-Docs		0
Refereed Papers and/or Book Chapters:	Published		81
	# of student authors/ co-authors		25
	Accepted but not yet published		9
	# of student authors/ co-authors		4
Presentations given at:	NASA Installations		5
	Nat'l or Internat'l Conferences		101
	# given by students		41
	Faculty Seminars		11
Panels (Advisory, Peer Review, Science Working Group) served on for:	NASA MUREP		4
	Other NASA		3
	Other Agencies		15
Patents:	Disclosures		--
	Applications		2
	Awards		1
Commercial Products which:	Entered Market		0
	Are in development		1
Enter Dollars leveraged, as a direct result of NASA MUREP funding, from:			
Research awards, new or renewal, pro-rated for the 12-month reporting period, from:	NASA, non-MUREP	Total	$ 496,070
		Equipment	$ 58,861
	Other Agencies	Total	$2,355,193
		Equipment	$ 344,288

Appendix 2

ADVISORY COMMITTEE MEMBERS

1. Dr. William Ballhaus
   Vice-President, Space Group
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Student Summer Program:

We have sought participation from students with the philosophy that 1) where possible, students from different schools would be paired together in order to foster a better learning environment and 2) The students would not only learn specific techniques, but the program would emphasize the scientific approach to problem solving. The program has been a great success with twenty four students working directly in the center projects during the summer of 1996. The schedule of activities that have been planned for this summer and will be scheduled for the future is outlined below.

8:00 - 9:30 a.m. M-F, STUDY PERIOD

This period will involve instruction by various faculty members on research topics as well as basic physics. For basic physics review topics, students will be assigned to one of several groups. Seniors and advanced juniors will work advanced problems in theoretical physics while sophomores and some juniors will begin their review with elementary problems on the level of Resnick and Halliday. This component allows for student-student as well as student-faculty interaction via discussions and problem solving. In addition, it will allow the staff to identify deficiencies in students' physics backgrounds and allow the staff to assist in eliminating some of the deficiencies.

9:00 - 5:00 p.m. M-Th, 9:00-3:00 F, RESEARCH PERIOD

The undergraduate students will work in teams of two along with a graduate student and a research staff advisor. The team approach has worked very well during the past five summers and has facilitated significant student-student and student-staff interaction. Students were expected to raise questions with one another as well as ask questions of their advisors. Research seminars may also be scheduled from time to time during this time period.

11:30 - 12:30 p.m. M-F, Lunch

3:00 - 5:00 p.m. F, Five Minute Oral Presentations on Research by each Student

A student from each team will alternate in giving a weekly presentation on the research activities for the week. They will be required to use overhead projectors as well as other presentation media and will be taught and required to practice good presentation techniques. The audience will consist of faculty, research staff, and students. The purpose of this component is to help develop student oral presentation skills, allow for greater student-student and student-staff interactions via questions on research and to allow all students to gain a better understanding of research done in the department.

In addition to the above activities, students will be expected to:

1) Maintain a laboratory log/diary to be turned in at the end of program.

2) Maintain a notebook on physics problems worked as a result of the physics review period
3) Present a final ten minute oral presentation on research work during program. The meeting will be styled on the same format as APS meetings.
4) Provide a (minimum five page) report on research work during program. The report must follow AIP or other association standards for a research paper.
5) Prepare and present a research presentation at a poster session.
6) Evaluate Program
7) Seek to give an oral presentation (seminar) on their research activities at their home institution during the following academic year
8) Participate in at least one site visit to a NASA research facility. In the past, this visit has been to Marshall Space Flight Center.

Students will be expected to participate in ongoing research projects and activities within the Center. Hence, they will work on material characterization techniques (bulk) and surface physics techniques. Supplemental funding will be sought to help support the student research activities.

FISK UNIVERSITY CENTER FOR PHOTONIC MATERIALS AND DEVICES

PUBLICATIONS (1992 - 1996)

Published or In Press

1. "Optical Determinations of the Direct Energy Gap in α-Mercuric Iodide at Elevated Temperatures", A. Burger and D. Nason, Journal of Appl. Phys., 71(6) (1992) 2717.

2. "Nonlinear Index of Refraction of Cu- and Pb-Implanted Fused Silica", R.F. Haglund, R.H. Magruder III, S.H. Morgan, D.O. Henderson, R.A. Weller, L. Yang and R.A. Zuhr, Nucl. Inst. Meth. Phys. Res. B 65, 405 (1992).

3. "A Review of Recent Measurements of Optical and Thermal Properties of α-Mercuric Iodide", A. Burger, S.H. Morgan, E. Silberman, D. Nason and A.Y. Cheng, Nucl. Inst. Meth. Phys. Res. A 322, 427 (1992).

4. "Optical and Infrared Spectroscopy of Laser Irradiated Bi Implanted SiO_2 Glasses", R.H. Magruder III, D.O. Henderson, S.H. Morgan and R.A. Zuhr, Proc. Mat. Res. Soc. 235, 383 (1992).

5. "Optical and IR Spectroscopy of Thermally-annealed Pb-implanted SiO_2", D.O. Henderson, S.H. Morgan, R. Mu, R.H. Magruder III, T.S. Anderson, J.E. Wittig, R.A. Zuhr, Proc. SPIE 1761, 191 (1992).

6. "A Study of Tellurium Precipitates in CdTe Crystals", Jayatirtha H. N., D. O. Henderson, A. Burger and M. P. Volz,Appl. Phys Lett., 62(6), (1993) 573.

7. "Surface Morphology Study on CdZnTe Single Crystals by Atomic Force Microscopy", M. Azoulay, M. A. George, A. Burger, W. E. Collins, and E. Silberman,J. Vac. Sci. and Technol. B 11(2), Mar/Apr 1993.

8. "Charge-Carrier Mobilities in $Cd_{0.8}Zn_{0.2}Te$ Single Crystals Used as Nuclear Radiation Detectors", Z. Burshtein, H. Jayatirtha, and A. Burger and J. F. Butler, B. Apotovsky and F. P. Doty, Appl. Phys. Lett., 62(26) (1993).

9. "An Observation of Nanotwin Lamellae in CdMnTe Crystal by Atomic Force Microscopy", M. A. George, M. Azoulay, W.E. Collins, A. Burger and E. Silberman, Journal of Crystal Growth, 130 (1993) 313.

10. "X-ray photoelectron Spectroscopy and Atomic Force Microscopy Characterization of the Effects of Etching $Zn_xCd_{1-x}Te$ Surfaces", M. A. George, M. Azoulay, H. N. Jaytirtha, A. Burger, W. E. Collins and E. Silberman, Surface Science, 296 (1993) 231.

11. "Surface Morphology Study on Mercuric Iodide Crystals by Atomic Force Microscopy", M. Azoulay, M. A. George, Y. Biao, A. Burger, and E. Silberman, and D. Nason, J. Vac. Sci. and Technol. B, 11(5) (1993) 1782.

12. "Optical Properties and Morphology Studies of Semitransparent Palladium Contacts on Mercuric Iodide Crystals", M.A. George, M. Azoulay, A. Burger, Y. Biao and E. Silberman and D. Nason and A. Cheng, Thin Solid Films, 236/1-2, (1993) 180.

13. "Atomic Force Microscopy of Lead Iodide Crystal Surfaces", M. A. George, M. Azoulay, H. N. Jayatirtha, A. Burger and E. Silberman, J. Cryst. Growth, 137 (1993) 299.

14. "Characterization of Thermally annealed Pb and Bi implanted Silica", D. O. Henderson, S. H. Morgan, R. H. Magruder, C. W. White, and R. A. Zuhr, Mat. Res. Soc. Symp. Proc. 1994.

15. "Formation of Photosensitive Materials by Implantation of Oxygen Ions in Silica", with R. H. Magruder, D. O. Henderson, C. W. White, and R. A. Zuhr, J. Non-Cryst. Solids, 159, 269 (1993).

16. "FEL Investigation of Energy Transfer in Condensed Phase Systems", D. O. Henderson, R. Mu, E. Silberman, J. R. Johnson, and G. S. Edwards Proc. SPIE-Int. Soc. Opt. Eng., 1854, 107 (1993).

17. "Optical Spectra of Pb Implanted Fused Silica", R.H. Magruder III, D.O. Henderson, S.H. Morgan and R.A. Zuhr, J. Non-Cryst. Sol. 152, 258 (1993).

18. "Characterization of Thermal Annealed Bi Implanted Silica", S.H. Morgan, D.O. Henderson, Pan, Z., R.H. Magruder III, R.A. Zuhr, Proc. Mat. Res. Soc. 279, 327 (1993).

19. "A Vibrational Analysis of Au Implanted Al_2O_3 Single Crystals: Ion and Thermal Annealing Effects", D.O. Henderson, S.H. Morgan, R. Mu, R.H. Magruder III, C.W. White, R.A. Zuhr, Proc. Mat. Res. Soc. 279, 439 (1993).

20. "Symmetry Lowering Due to Site-Occupation Disorder in Vibrational Spectra of Gehlenite, $Ca_2(AlSi)AlO_7$", Z. Burshtein, Y. Shimony, S. Morgan, D.O. Henderson, R. Mu, E. Silberman, J. Phys. Chem. Solids 54(9), 1043 (1993).

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